A Decision Support System for Fostering Smart Energy Efficient Districts

Full Paper

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Abstract

The role of ICT is becoming prominent in tackling some of the urban societal challenges such as energy wastage and increasing carbon emissions. In this context, the concept of DAREED aims to deliver an integrated decision support system (DSS) to drive energy efficiency and low carbon activities at both a building and district level. The main aim of this paper is to present the technical concept of the Best Practices recommendation component of the DAREED system. This component seeks to compare and identify existing best practices to recommend practical actions to various stakeholders (e.g. building managers, citizens) in order to improve energy performance considering the global needs of a building. This paper also discusses the context of the three field trial sites (based in UK, Spain and Italy) in which the DAREED platform along with the best practices tool is to be tested and validated.

Keywords: Information and Communications Technology (ICT), Decision Support Systems (DSS), Multi-objective optimization (MOOP), Energy Efficiency; Smart City

Introduction

Information and Communication Technologies (ICTs) are able to provide promising solutions to address the complex challenges related to the management of sustainability in cities (Zarli and Rezgui, 2013). In terms of energy management in cities, ICT has made it possible to access real-time information about building environmental characteristics and energy consumption (NIST, 2010). At district level, information about district heating and cooling and electricity grid can be also accessed. In the smart city context, one of the significant issues is the reduction of energy waste and carbon emissions in the energy distribution network as well as single buildings and houses (Patti et al., 2014; Karnouskos, 2010). ICT is recognised as being able to facilitate addressing issues such as energy waste and it is acknowledged that energy-positive buildings, districts, and neighbourhoods will be empowered by electronic (embedded) components, software and ICT systems and infrastructures (Zarli and Rezgui, 2013).

The usage of ICT systems allows for energy efficiency improvements through a holistic approach, which produces more synergy working with partners on strategy, vision and long-term actions (Sivarajah et al., 2014). At system architecture level, barriers reside in availability of spatial data, limited access to operational/dynamic data and database lack of integration. However, in current status of building planning, tools focus in energy aspects at single-building level, while design tools do not integrate enough reliable prediction of performance during operation. Furthermore, energy efficient ICT solutions are not available to involve key stakeholders (e.g. citizens, building owners, energy suppliers, public administrations) in the planning and neighbourhood from the energy efficiency view point. Smart metering, where applied, is for monitoring and billing, but not for decision-support at neighbourhood level. Lack of awareness of the potential ICT solutions for energy efficiency and high cost of the integration of ICT in neighbourhood level are some barriers towards the involvement of final users in district energy management.

Such barriers and the paucity of ICT solutions taking a holistic approach confirm the need for an integrated ICT solution for driving energy efficiency at both a building and district level. Therefore, the main objective of DAREED (Decision Support Advisor for Innovative Business Models and User Engagement for Smart Energy Efficient Districts) concept is to develop an integrated ICT platform by exploiting existing ICT tools to support decision making for policy makers, citizens and other stakeholders in order to help them achieve energy efficiency. In doing so, DAREED seeks to foster smart cities through innovative integration and application of ICT tools. This paper presents the technical concept of the DAREED system with the main focus on the Best Practices recommendation component of the platform that serves as an effective decision support system for driving energy efficiency at both a building and a district (city) level. The objective of the best practices tool is to compare and identify existing best practices using multi-objective optimization (MOOP) approach to recommend actions in order to optimize energy profile and raise energy efficiency class for each building.

The rest of this paper is organised as follows. Following this introduction, the paper presents a literature review surrounding existing ICT solutions for driving energy efficiency practices. This is followed by a description of the DAREED system architecture and a discussion highlighting the Best Practices Recommendation tool. The subsequent section provides the context of where the research is going to be experimented. Finally, the paper concludes by highlighting the theoretical and practical implications of the study.

Literature Review

Decision Support Systems for Energy Management

Energy management is a key process of energy efficiency as it is significant for the effective operation of a country energy sector and for its environment's protection (Doukas et al. 2007). In the existing literature there are various studies (e.g. González et al., 2012; Lazaroiu et al., 2012; Niemi and Mikkola 2012), that focus on supporting energy saving, user profiling, demand aggregation and energy management using ICT solutions. Decision support systems (DSS) in this context also play a significant role to help support decision making in the field of energy management. According to Shim et al., (2002), DSS are computer technology solutions that can be used to facilitate complex decision making and problem solving. Doukas et al. (2007) presented an intelligent decision support model using rule sets for building energy management aiming at guarantying the desirable levels of living quality as well as energy savings for environmental protection. The system enables central monitoring of energy consumption in buildings, by translating the building's energy knowledge into several rules and finally into electronic commands to actuator devices. More recently, Bouffaron and Koch (2014) offered an analysis of the couple modelling-monitoring on a district level, emphasizing the benefits of integrating long-term monitoring approaches based upon on-site measurements. The study focuses on the potential of monitored district heating systems. Heat represents a major fraction of modern society's energy needs: the installation or upgrading of district heating systems with advanced and integrated solutions has the potential to reduce energy use and environmental pollution.

There are also various research projects that exist to address the issue of improving energy efficiency using ICTs and studies relating to these projects (e.g. Patti et al., 2014; Runardotter and Holst; 2013) have also emerged in the literature. From a building management perspective, the FCINT concept (Ontology-based Service Composition Framework for Syndicating Building Intelligence) provides a service-oriented approach for control and management of building facilities via an intelligent controller (Marian et al., 2013). The concept presents an intelligent building management framework built which consists of a simple controller that can interoperate with a variety of devices through device services, allows users to design and compose schedules and policies. On the other hand, from a district level perspective, Klebow et al., 2013 report the concept of EEPOS (Energy management and decision support systems for Energy POSitive neighbourhoods) that aims at developing a new system for energy management and automated load control on the neighbourhood level. Runardotter and Holst (2014) discuss the CASSANDRA concept that aims to develop a platform for realistic modelling of the energy market stakeholders by providing its users the ability to test and benchmark working scenarios that can affect system operation, company policies, and environmental regulations at different levels of abstraction, from a basic level (single consumers behaviour) up to large consumer areas (e.g. a city).

Although, there are various studies leveraging DSS in the energy management context as highlighted above, most of these studies tend to focus only at a building level or district perspective. The existing studies have not taken a holistic approach to tackle the issues from both a building and district level which is novel to the DAREED concept.

Multi-objective optimization (MOOP) approach to improve Energy Efficiency

The multi-objective optimization or MOOP (Multi Objective Optimization) is a process that aims to find the optimal solution of a problem that consists of multiple objectives (Schaffer, 1987). The first studies on how to solve the MOP (Multi Objective Problem) began in the second half of the '900 and have increased considerably over the years. This is due to the fact that almost all of the real problems cannot be attributed to an SOP (Single Objective Problem), as there are often multiple aspects to be taken into account, most of the sometimes in contrast among them. In the existing literature there are many studies (e.g. Wright and Loosemore 2001; Carlucci and Pagliano 2013) that highlight the of use multi-objective optimization algorithms to optimize energy profile and raise energy efficiency.

A study by Wright and Loosemore (2001) investigates the application of a multi-objective genetic algorithm (MOGA) search method in the identification of the optimum pay-off between the elements of the building design problem. The results of this research presented the pay-off characteristic between the daily energy cost and zone thermal comfort. Nassif et al. (2005) discusses the problem of optimization using a multi-objective genetic algorithm which will permit the optimal operation of the building's mechanical systems when installed in parallel with a building's central control system. Using this proposed optimization process, the supervisory control strategy setpoints, such as supply air temperature, supply duct static pressure, zone air temperatures etc. are optimized with respect to energy use and thermal comfort.

Another study by Diakaki (2010) includes decision supporting techniques, such as multicriteria-based decision making methods combined usually with simulation to assist the reaching of a final decision among a set of alternative actions predefined by the building expert. This approach evolved combining simulation with notions and concepts originating from the scientific area of multi-objective optimization. This study shows how it is feasible to develop a stand-alone tool for the decision improvement of the energy efficiency in buildings. More recently, Carlucci and Pagliano (2013) refer to an optimization procedure that aims to support the design of buildings to almost zero energy. The procedure described in this study uses the techniques of optimization to identify the thermo-physical properties of the components of the building envelope and passive systems of the building, which minimize thermal discomfort evaluated according to specific metrics during the summer and during the winter. This process maximizes the energy performance of the building according to the specific climatic, local and profiles of use of the building by the occupants.

The existing studies discussed above highlight that the approach of energy management optimization at a district level is neglected. This approach could substantially modify results from a specific optimization problem considering potential of net-energy balance and its associated business models. Additionally most of the optimization problems have not been based on real time data reducing the possibilities of establishing strategies regarding energy prices or energy storage (both thermal or electric storage). Therefore, the proposed concept of DAREED in this paper aims at bridging the gap or transferring the expertise from building level to district level increasing the possibilities of the optimization.

DAREED Context and System Architecture

DAREED strives to foster the concept of sustainable energy district considering buildings not as an individual energy-consuming element but as a complex network element, allowing the introduction of macro strategies in the district level (Sivarajah et al., 2014). This section provides a general description of the proposed DAREED service-oriented architecture (SOA) architecture at a systematic level as illustrated in figure 1.

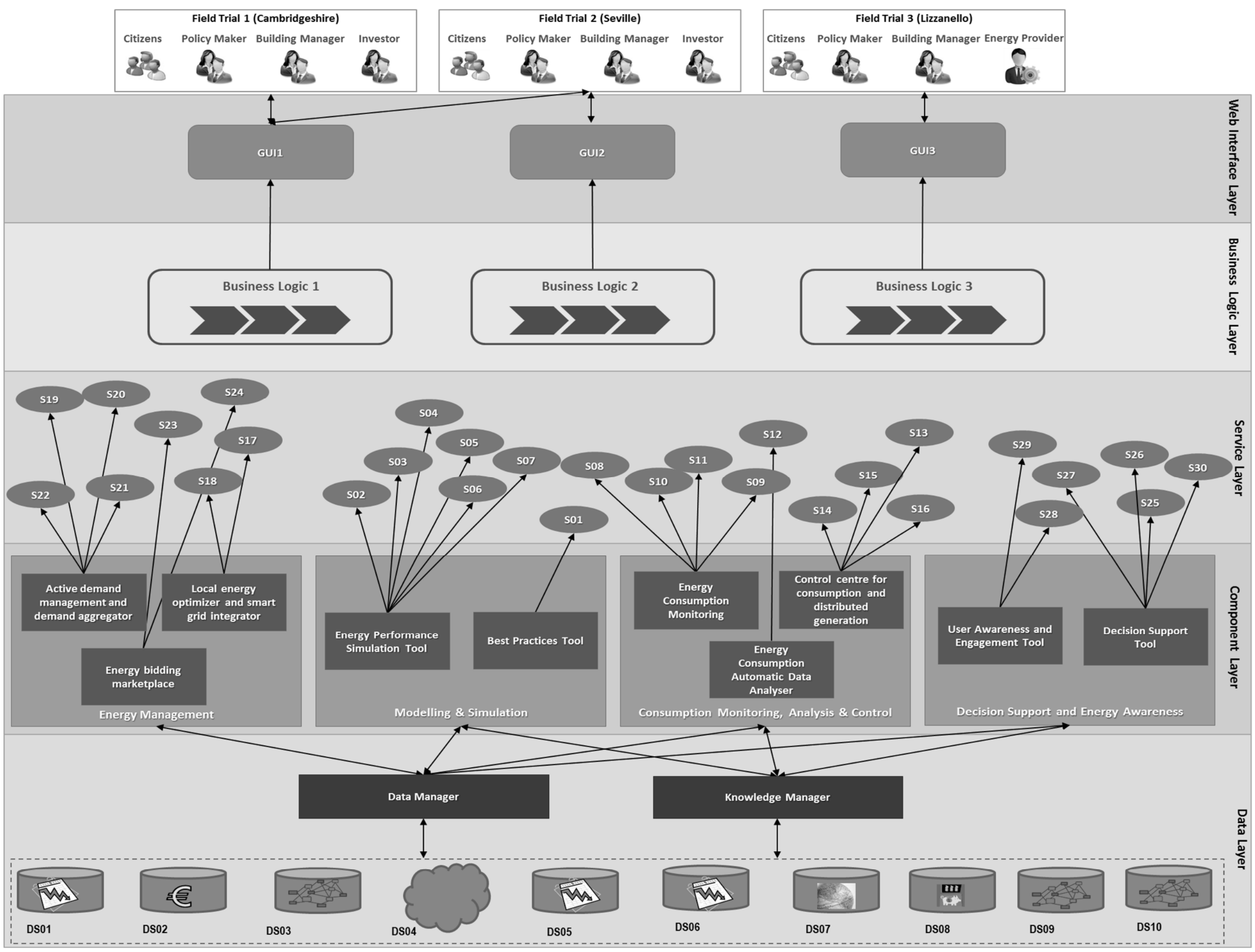

Figure 1. DAREED System Architecture

A brief description of each of the Interface layers depicted in the above system architecture in figure 1 are discussed below.

Web Interface Layer:

The Web interface layer provides a personalization-enabled Web Graphical User Interface (GUI) for the relevant end-users of the platform (i.e. Citizens, Building Managers, Energy Providers, Investors and Policy Makers). Each of the end-user has different access rights.

Business Logic Layer:

The business logic (i.e. use cases) layer defines the relationships and interactions among services in service layer in order to match the business requirements. It serves service orchestration that enables composition and coordination of services into long-running transactions and collaborative business processes.

Service Layer:

Service layer includes number of services that carry out individual business function. It provides conceptual bridge between higher level layers (i.e. Web Interface and Business Logic Layer) and lower level layers (i.e. Component and Data Layer) (Bieberstein, 2005). The services included in the layer represent the critical technical functions needed to fulfil the business requirements. The detailed lists of the services that are to be delivered by DAREED platform is presented below in Table 1.

Component Layer:

This layer represents different applications having specific function scopes. It includes both the existing applications and components that will be developed as part of the DAREED system. Each application has a data adapter, which provides access to the different data sources in data layer. The data adapter imports and transforms the data from the data layer into the application specific schema. The applications and components in the layer are loosely coupled and work independently. The following are the core components that are part of this layer

- Modelling and Simulation
- Energy Management
- Consumption Monitoring, Analysis and Control
- Decision Support and Energy Awareness

Data Layer:

Data layer contains different data stores used by DAREED system as the data sources. It includes data from different existing systems, such as existing building management systems, existing tariff calculation systems, data acquisition systems of energy generators, etc., which are distributed throughout different stakeholders, e.g. energy providers, building owners, district authorities, etc. The data sources also have different data schemas and formats. They could be in XML, relational database, or ontology formats.

The following table 1 summarises the list of services (functions) that is to be provided by each of the components identified as part of the DAREED system architecture. Each service has been given a unique identification number that is labelled as SID (i.e. Service ID).

Name of Main Components and Sub-Components	SID	Services (functions)
Modelling & Simulation: *Best Practices Tool*	S01	Identify the best practices to optimize energy profile for a building
Modelling & Simulation: *Energy Performance Simulation Tool*	S02	Evaluate energy performance on district level
	S03	Forecast energy consumption on district level
	S04	Forecast energy production on district level
	S05	Forecast system performance and cost in a district
	S06	Forecast hourly use using weather information on district level
	S07	Update repository containing good practices in a district
Consumption Monitoring Analysis & Control: *Energy consumption monitoring*	S08	Monitor energy consumption at building and district level
	S09	Store aggregated energy information from different measurement devices
	S10	Aggregate data query
	S11	Visualize energy consumptions and comparisons between them
Consumption Monitoring Analysis & Control: *Energy consumption automatic data Analyser*	S12	Automation alarm for energy miss-consumption
Consumption Monitoring Analysis & Control: *Control centre for consumption and distributed generation*	S13	Forecast energy bill
	S14	Send energy prices for next period
	S15	Send signal to local controllers of distributed generation
	S16	Level of acceptance of proposed generation plan
Energy Management: *Local energy optimizer and smart grid integrator*	S17	Manage and optimize energy flow
	S18	Manage rule base for best energy consumption practices
Energy Management: *Active demand management system and demand aggregator*	S19	Provide communication between energy suppliers, energy services and consumers
	S20	Manage consumptions based on comfort parameters and tariffs
	S21	Manage power reduction when load problems are foreseen
	S22	Adapt energy consumption to dynamic prices
Energy Management: *Energy bidding marketplace*	S23	Provide list of different energy tariffs
	S24	Make suitable bid of consumer based on their consumption patterns
Decision Support and Energy Awareness: *Decision Support Tool*	S25	Choose tariffs, added value services, and efficiency improvements options for a set of energy units
	S26	Optimize a tariff specification, for a set of energy units
	S27	Find an incentive plan to improve the behavior of a set of energy units
Decision Support and Energy Awareness: *User Awareness and Engagement System*	S28	Analyze energy cost
	S29	Share energy efficiency news and best practices on social networks
	S30	Intelligent search engine

Table 1. Services to be provided in DAREED system

The next section discusses the *best practices recommendation tool* as part of the main Modelling and Simulation component. It is worth noting that the remaining components and the services of DAREED presented in Table 1 are not reported in this article as it is not the objective of this paper.

Best Practices Recommendation Tool

The aim of this recommendation tool is to compare and identify the best practices to optimize energy profile and raise energy efficiency class for each building. This tool produces a detailed report of recommended actions to improve performance, considering the global needs of the building and the adoption or integration of renewable energy sources. The Best Practices recommendation tool consists of three logical blocks.

The first logical block represents the input data of the simulation block. These data are building general data, climatic zones where the building resides, construction period of the building, etc. The second logical block represents the simulation of the building energy efficiency, which receives in input weather data and the Best Practices Catalogue, too. Outputs of each simulation are sent in input to Energy Efficiency Algorithm logical block. Energy Efficiency Algorithm logical block making use of multi-objective algorithms returns the output of the Best Practices in order to maximize the energy efficiency of the building. The block diagram of the Best Practices Tool is shown in the following figure:

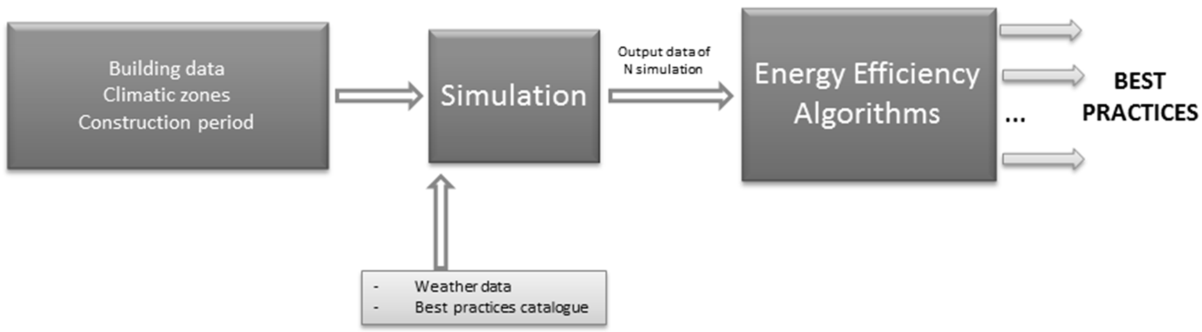

Figure 2. Block Diagram of Best Practices Recommendation Tool

Inputs of Simulation of each building

Energy model will have building data inputs such as for climate, envelope; HVAC ((heating, ventilating, and air conditioning) system, lighting system, etc. and weather data. Before proceeding to the step of multi-objective optimization, it is necessary to perform "N" simulations in order to provide a variance to some input parameters and other parameters kept constant. The Best Practices Catalogue for energy efficiency and production consists of a set of best practices that improve the energy efficiency of a building.

The variables that can be changed in the model of the building (Ferreira et al., 2013), in order to improve its energy efficiency are for example:

- door type; window type; vertical closures data; orientation of windows; heating system; cooling system; lighting system; HVAC temperature set point; HVAC humidity set point; renewable energy sources, etc.

The improvement of energy efficiency is obtained achieving certain objectives, taking into account some optimization criteria. Some of the possible criteria are listed below:

- annual energy cost/operational cost; annual energy cost/operational cost (present value of life time energy saving, PVLTES); investment cost (IC); heating energy needs or consumption; thermal comfort; indoor air quality level; CO2 emission from global primary energy consumption; maintenance cost; greenery; thermal and moisture protection; innovative energy technology, etc.

The execution of multi-objective algorithms allows achieving the objectives that contribute to improving the energy efficiency of a building. Some objectives are:

- minimize/optimize energy costs, thermal energy needs/consumption, domestic hot water energy needs/consumption, lighting energy needs/consumption; improve indoor environmental quality; reduce CO_2 emissions; optimize renewable energy balance; increase the use of green materials.

Building Simulation and Optimisation Approach

In the DAREED platform, the end-user (e.g. building manager) will be able to include some general building data, such as the orientation of the building, the climatic zone, the type of building, the number of floors, the number of occupants, the total heated area, the illuminated area, the heating winter temperature and the cooling summer temperature. Following this, the building manager can insert the vertical closures construction materials, the horizontal closures construction materials and window materials. Finally, the user can insert the type of HVAC plant with its electrical consumptions and parameters. The performance building simulation is carried out after having defined certain parameters to vary in order to obtain different configurations of buildings. After this step the building manager can select the objective functionsuch as heating and cooling. Heating value must not be greater than 100000 kWh and cooling value must not be greater than 1000 kWh.

Another example of the many objective functions that could be considered is the thermal comfort, which is calculated by the PMV (Predicted Mean Vote) that is a mean of a large group of people exposed to the thermal conditions of interest and providing a rating on the seven point of the following thermal sensation scale (Novakovic et al., 2005):

- +3: Hot;
- +2: Warm;
- +1: Slightly Warm;
- 0: Neutral;
- -1: Slightly Cool;
- -2: Cool;
- -3: Cold.

$$PMV = (0.303\ e^{-0.036M} + 0.028)(H - L)$$

where, H is the internal heat production rate of an occupant per unit area meassured in W/m^2, L is all the modes of energy loss from body meassured in W/m^2 and M is the metabolic rate per unit area, measured in W/m^2.

The predicted percentage dissatisfied (PPD) is related to the PMV and is based on the individual variation in response for a given set of conditions.

In Fanger method (Fanger, 1970) PPD is calculated with the following equation:

$$PPD = 100 - 95e^{-(0.03353PMV^4 + 0.2179PMV^2)}$$

Thermal comfort calculation demonstrates that the occupants of the building have an impact on energy consumption. The Best Practices tool will produce optimal solutions with the use of NSGA-II algorithm which is described in the following section, where only one of the produced results is the best solution. This solution could consist of an optimal building configuration with certain type of building materials, thickness of wall, occupant density, lighting power density, equipment power density, etc.

Energy Efficiency Algorithms: Multi-objective optimization

The first approaches that were applied for solving multi-objective problem (MOP) consist in tracing the problem to a SOP, possibly using information such as the order of preference of objectives. When facing a MOP, obtaining a unique solution is possible only if the objectives are not in conflict with each other, but in most practical cases this does not happen. So in MOOP it has to do with a set of solutions, and no longer a single solution. The approach adopted is defined as ideal which aims at finding in a first step a set of solutions, without relying on any type of preference in homes. Once obtained the set of solutions, in the second phase are exploited any preferences to select the best. The sole purpose of the first phase is to find a highest possible number of different solutions.

The MOOP, such as SOOP (Single Objective OPtimisation), is characterized by a space of decisions multidimensional, then the space characterizes all the values that the decision variables (inputs) can take. If optimization is not bound, that space is unlimited. The substantial difference with the SOOP is that also the space of the objectives is multidimensional, then is the space that represents the value that the objective functions can take. The correspondence between the two spaces is not bijective and the report that binds them is often non-linear, so the mapping is not trivial. Formally MOOP is defined as:

$$\begin{cases} Min/Max & f_m(x) & m = 1,2,...,M \\ & g_j(x) \geq 0 & j = 1,2,...,J \\ & h_k(x) = 0 & k = 1,2,...,K \\ & x_i^{(L)} \leq x_i \leq x_i^{(U)} & i = 1,2,...,n \end{cases}$$

Figure 3. Generalized form of MOOP (source: Moretti and Panzieri, 2013)

where:

M is the number of objectives, *J* represents the number of constraints, *K* is the number of equality constraints, *n* is the number of decision variables, $x^{(L)}$ and $x^{(U)}$ are the bound of the decision variables.

Since in the case of MOOP are confronted more objectives, defining which solution is better than another is not immediate as in SOOP. For which, it is introduced the concept of Pareto dominance that a solution x_1 dominates ($\triangleleft$) the solution x_2 if:

1. $f_i(x^{(1)}) \ntriangleright f_i(x^{(2)}) \quad per \quad i = 1 \ldots M$
2. $\exists i \mid f_i(x^{(1)}) \triangleleft f_i(x^{(2)}) \quad per \quad i = 1 \ldots M$

Figure 4. Dominance criterion (source: Moretti and Panzieri, 2013)

Multi-objective algorithms

The Multi-objective algorithms or MOA (Multi Objective Algorithm) are a class of algorithms that optimize the MOP (Multi Objective Problem), and are divided into two types: approach based on preferences or approach multi-objective.

The first approach consists in the method of weighted sum, based on preferences, which is assigned a weight to each objective and the objective is to minimize the function that encompasses all the objectives, the MOP is reduced to the following equation.

$$\begin{cases} Min/Max & F(x) = \sum_{m=1}^{M} w_m f_m(x) & m = 1,2,...,M \\ & g_j(x) \geq 0 & j = 1,2,...,J \\ & h_k(x) = 0 & k = 1,2,...,K \\ & x_i^{(L)} \leq x_i \leq x_i^{(U)} & i = 1,2,...,n \end{cases}$$

Figure 5. Method of Sum Weighing (source: Moretti and Panzieri, 2013)

This approach is highly dependent on the initial choice of the weights assigned to the objective functions, also it is not effective for non-convex problems, since it has been shown that there exist solutions that this algorithm cannot find.

The second approach is a method based on constraints. The idea is to maximize one of the objective functions, while the other are converted into constraints of the problem as shown in the following equation:

$$\begin{cases} Min/Max & f_\mu(x) & \\ & f_m(x) \leq \epsilon_m & m = 1,2,...,M \; m \neq \mu \\ & g_j(x) \geq 0 & j = 1,2,...,J \\ & h_k(x) = 0 & k = 1,2,...,K \\ & x_i^{(L)} \leq x_i \leq x_i^{(U)} & i = 1,2,...,n \end{cases}$$

Figure 6. **Method of constraint (source: Moretti and Panzieri, 2013)**

Also, this approach is influenced by the choice of the bond, but also manages to solve non-convex optimization problems. The type of algorithm to be used for multi-objective optimization as part of the Best Practices tool is NSGA-II, a multi-objective genetic algorithm to maximize the energy efficiency. NSGA-II is a multi-objective evolutionary algorithm (EAs) that use non-dominated sorting (Deb et al., 2002).

Simulation results on difficult test problems show that the NSGA-II, in most problems, is able to find much better spread of solutions and better convergence near the true Pareto-optimal front compared to Pareto-archived evolution strategy and strength-Pareto EA—two other elitist MOEAs that pay special attention to creating a diverse Pareto-optimal front.

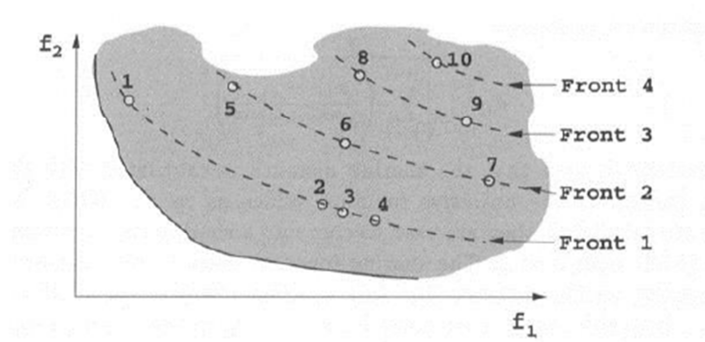

Figure 7. NSGA-II, example of sorting by levels (source: Moretti and Panzieri, 2013)

In the NSGA-II, the population are sorted according to an ascending order of non-dominance and the algorithm operates a classification of the entire population, which are divided into classes or rank.

NSGA-II makes use of two concepts; (1) Density Estimation and (2) Crowded-Comparison Operator. Density Estimation ($i_{distance}$) provides an estimate of the density of solutions surrounding a particular solution in the population. The average distance of two points on either side of this point along each of the objectives is calculated and serves as an estimate of the perimeter of the cuboid formed by using the nearest neighbors as the vertices (call this the crowding distance).

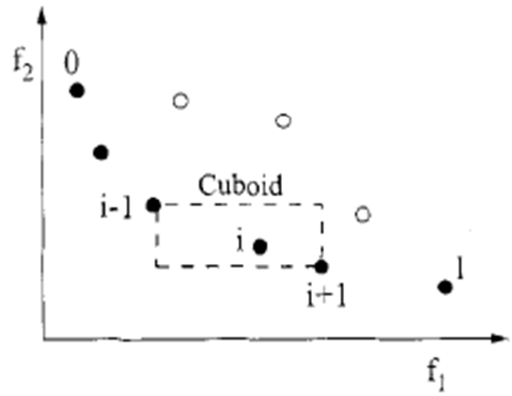

Figure 8. Crowding-distance calculation (source: Moretti and Panzieri, 2013)

The crowding-distance computation requires sorting the population according to each objective function value in ascending order of magnitude. Points marked in filled circles in above figure 8 are solutions of the same nondominated front.

Crowded-Comparison ($\prec_n$) guides the selection process at the various stages of the algorithm toward a uniformly spread-out Pareto optimal front. Assume that every individual "*I*" in the population has two attributes:

1) non-domination rank (i_{rank});
2) crowding distance ($i_{distance}$)

Is defined partial order $\prec_n$ as:

$$i \prec_n j \qquad \text{if}(i_{rank} < j_{rank})$$

$$\text{or } ((i_{rank} = j_{rank}) \text{ and } \quad (i_{distance} > j_{distance})$$

This means that between two solutions with different non-domination ranks is prefer the solution with the lower (better) rank.

The pseudocode of the NSGA-II algorithm is the following:

```
fast-non-dominated-sort(P)
for each p ∈ P
   S_p = ∅
   n_p = 0
   for each q ∈ P
      if (p ≺ q) then                   If p dominates q
         S_p = S_p ∪ {q}                Add q to the set of solutions dominated by p
      else if (q ≺ p) then
         n_p = n_p + 1                  Increment the domination counter of p
   if n_p = 0 then                      p belongs to the first front
      p_rank = 1
      F_1 = F_1 ∪ {p}
i = 1                                   Initialize the front counter
while F_i ≠ ∅
   Q = ∅                                Used to store the members of the next front
   for each p ∈ F_i
      for each q ∈ S_p
         n_q = n_q − 1
         if n_q = 0 then                q belongs to the next front
            q_rank = i + 1
            Q = Q ∪ {q}
   i = i + 1
   F_i = Q
```

Figure 9. NSGA-II pseudocode (source: Moretti and Panzieri, 2013)

In sum, NSGA-II is the type of algorithm that is to be used for multi-objective optimization as part of the Best Practices tool as discussed above. The next section of this paper highlights where the DAREED platform as a whole is to be experimented and validated.

Field Tests and Validation

This section presents a discussion of the field tests that are yet to be conducted for the tools that are currently under development as part of the DAREED system. Two key aspects were taken into consideration in order to define the field tests (pilot sites) that will help evaluate and validate the DAREED platform and its services such as the Best Practices tool.

1. **Benefits for the specific pilot according to their needs**: In this sense public building plays a main role because of the key stakeholders involved in this research are owners/managers of these building and therefore are able to meet their needs and also gaining access to these buildings for the field tests are easier.
2. **Suitable for the goals of the project**: To do so, buildings have to be representative enough in their areas. The diversity of uses, ages and external conditions linked to field trial location (transnational approach) will ensure the impact of the pilot tests planned.

In the validation phase, the platform will be tested in real cases involving stakeholders such as energy suppliers; building managers; district managers and citizens. In this process, opinions from different users will be collected and used to adjust or re-design both the information and interfaces to maximize understanding and achieve the final purpose of the platform which is to increase energy efficiency at a district (city) level. Taking the abovementioned factors into account, field tests have been selected so that it better represents the characteristics of the districts or those with the higher impact in terms of district activities and finally considering the ease of accessibility to the building management staff and information obtainable. Moreover, a contextual example of a potential end-user using the Best Practices tool as part of the DAREED system is provided in Appendix A to provide a better understanding of the use of this tool as there is no real data available at this stage.

Seville, Spain:

The history of Seville and artistic legacy is one of the main economic drivers of the city and boost tourism sector; it is an enhancer of sectors such as cultural, educational or service companies. For that reason the chosen field trial site has been an old town district based in the city of Seville, one of the 11 administrative districts, elected by its relevance for the city and for its replicability to other historic cities. Old town district in Seville has been selected for its diversity of uses. Due to the large surface area of the district centre, the proceedings have focused on the historic area of the city. In this limited space, different uses have been identified, which provides access to an acceptable sample to extrapolate to the rest of the city. Social housing buildings and the incorporation of other types of housing (and flats) such as monumental buildings survey and analysis of administrative buildings and incorporating data from the city of sport will be used for the field tests based in Spain.

Cambridgeshire, United Kingdom:

In the United Kingdom, the field tests will take place in the city of Cambridge and the administrative centre of the county of Cambridgeshire, England. It lies in East Anglia, on the River Cam, about 50 miles (80 km) north of London. From a building level perspective, the state-of-the-art Cambridge Central Library, a flagship of the county's public library service has been chosen as the field test site. The Energy Management Team at Cambridgeshire County Council has installed metering that enables the monitoring of electricity and gas consumption on a half-hourly basis in all Cambridgeshire libraries. This will be very useful for the comparison of before and after the implementation of the DAREED developments. One of the key outcomes of the DAREED project will be better communication in terms of promoting smarter energy behaviour by users, which can be made available across all libraries and library access points.

For the district level validation, Luminus, a not-for-profit affordable housing provider established in 2000, based in Huntingdon, Cambridgeshire has been selected as the field test. Luminus serve more than 45,000 people, in 7,500 homes throughout the east of England. It is likely that the majority if not all of homes used in the DAREED pilot will fall into the General Needs category.

Lizzanello, Italy:

In Italy, the City of Lizzanello, in the province of Lecce, a small town which has about 12,000 inhabitants, including the hamlet of Merine has been selected as the third and final field test site. Considerable attention is turning to energy savings with a view to optimize the economic resources and have clean energy. In line with this focus, the municipality of Lizzanello has installed alternative energy systems (solar panels) on some property owned by the city and still have made thematic meetings (the last one was held in September 2012) in order to urge the adoption of such systems for energy efficiency. The Historical Centre of Lizzanello (HCL) constitutes the old part of Lizzanello, founded probably in 1210 A.D., with a population of around 6000 inhabitants. In DAREED the idea is to coordinate an action that involves mixed buildings and space to represent a typical condition of mixture in age and genres that characterize many small towns in the south of Italy.

Concluding Comments and Contributions of Study

This paper presented the concept of the DAREED system with the key discussions surrounding the Best Practices Recommendation component architecture and its functional capabilities. In conclusion, DAREED system seeks to apply validated optimization algorithms based on real-time data acquisition allowing stakeholders (namely energy users and energy managers) to minimize their energy consumptions and in particular adjust energy plans on a daily or monthly basis according to foreseen weather conditions and historical information. In addition, taking into account the new paradigm of the European electricity market in which energy prices vary dynamically depending on offer and demand patterns, the platform will provide a service to reduce economic cost in the energy supply through tariff recommendations and demand management amongst other strategies.

This study is an on-going research effort and therefore as part of the future research, empirical data will be collected from the end-users (e.g. citizens, building managers and public bodies) of the platform from the proposed field trial sites to evaluate and validate the system. In doing so, this study will inform practitioners and the academic community about the significance of the energy efficiency tools such as DAREED and its impact on the success and take-up of the services offered for the end-users. The contributions of this research will be of benefit to both academics and practitioners engaged in DSS and smart city research especially from an energy efficiency context. This paper contributes to the current understandings of e-Government literature in terms of how ICT especially DSS can help stakeholders such as public authorities, building managers, citizens and policy makers to achieve and drive energy efficiency. From a managerial perspective, the paper offers valuable insights into the design of the innovative DSS platform and the potential real world application in order to address societal challenges. The contribution of the current work in comparison with the existing commercial tools is the combination of different energy services oriented to multiple stakeholders and the capacity of the platform for providing recommendations and understanding the necessities of those different stakeholders.

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Appendix: A Contextual Example Case of using DAREED Best Practices Tool

Peter owns an old residential building in the downtown that he succeeded from his family. Currently 8 families live in the building. Peter hired a builder couple of years ago to repair if something goes broken, but he is not in the position to do large improvements like isolation of the building. Peter observes that the electricity bills of the families increase with each year but is afraid that the professional consulting services for energy efficiency improvement of the building will cost him too much. So, he decides to register to a new IT platform, where he can easily understand what the consumption pattern of the building is and get an initial idea on what the different possibilities are. Peter agrees to register to the DAREED platform as a building manager (owner) and to install specific hardware devices for monitoring the energy consumption and Co2.

Few months later, he log-ins again on the platform and sees detailed information on his building – detailed consumption pattern per type of activity (lighting, heating, household activities), comparative tables between different categories etc. The platform suggests to Peter to upgrade the window isolation as a first measure and install PV on the roof of the building. After providing the suggestion, the platform calculates what the total funding needed will be for these activities, what the expected period of return is and how much he can really save. With the information related to his consumption profile, Peter, can go to professional authorities for further calculations and save money from unnecessary preliminary communication.